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MEMORANDUM

From: Bill Jemison
To: Dr. Daniel Tam, ONR
Date: 1/31/2014

Subject: Progress Report 013–
Chaotic LIDAR for Naval Applications: FY14 Q1 Progress Report (10/1/2013– 12/31/2013).

This document provides a progress report on the project "Chaotic LIDAR for Naval Applications" covering the period of 10/1/2013–12/31/2013.

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FY14 Q1 Progress Report: Chaotic LIDAR for Naval Applications

This document contains the following three sections:
- I.   Progress Summary for FY14 Q1
- II.   Detailed Description of Work Performed in FY Q1
- III.   Short Work Statement for FY14 Q2.

I.   Progress Summary for FY14 Q1

Work completed in the first quarter of FY14 includes our first system chaotic lidar system experiments in turbid water.

We have obtained 5 mm average accuracy and ±4 cm resolution through up to 10 attenuation lengths of water. This work was done with a small-aperture receiver to test the absorption-limited performance of the system, and we are preparing to perform a similar experiment with a large-aperture receiver to determine the effectiveness of the system in scattering-limited environments.

Additionally, we have advanced the preparation necessary to perform channel characterization using chaotic LIDAR by incorporating several upgrades to the chaotic receiver and using advanced signal processing techniques to fully separate the backscatter from the target in the chaotic LIDAR return signal.

Luke Rumbaugh received second place in the Ocean's '13 student paper contest.

A more detailed description of the work is provided below.

II.   Detailed Description of Work Performed
Ranging in Turbid Water

In our last report, we demonstrated high performance unambiguous ranging in clear water using the chaotic fiber laser developed under this program. Experiments were repeated in turbid water using a small aperture receiver. The turbidity was varied from 5 to 11 m^{-1}. High values of turbidity were used because of the short length ($\sim$ 1m) of the available test tank. We are in the process of setting up a 20m long test tank which will allow greater experimental flexibility.

The experimental ranging setup is shown in Figure 1. The optical transmitter is our frequency doubled chaotic fiber laser. A digitizing oscilloscope was used to collect data required for the autocorrelation-based signal processing. Post-processing of the data was also performed to digitally filter the receive signal to reduce the effect of scattering and to obtain higher range accuracy.

Figure 2 shows a representative experimental result which show unambiguous ranging though 10 attenuations lengths (5 attenuation length standoff range) with c= 5.5 m^{-1}. The range resolution was +/- 4cm and the average range error was less than half a centimeter. This performance is determined by the bandwidth of the data collection system and not the chaotic laser.

William D. Jemison, Professor and Chair, PO Box 5720, Clarkson University, Potsdam, NY 13699-5720
315-268-6509, Fax 315-268-7600, wjemison@clarkson.edu

While the small aperture receiver did collect some scattered light – we estimate that about half of the optical power reaching the photodiode was scattered – the experiment is attenuation limited. Thus this can be considered a test of the system in absorption-limited scenarios, such as would be faced in long-range open ocean operation
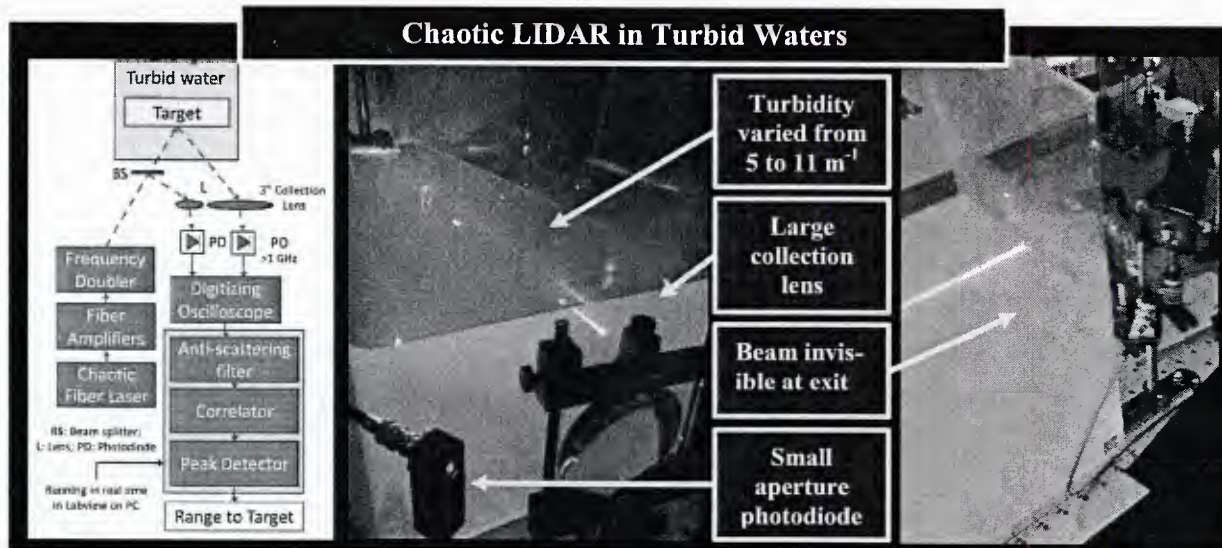

Figure 1. Chaotic LIDAR in turbid water. *Left:* Block diagram for absorption-limited ranging at 10 total attenuation lengths. *Right:* Photographs of operation in turbid waters.
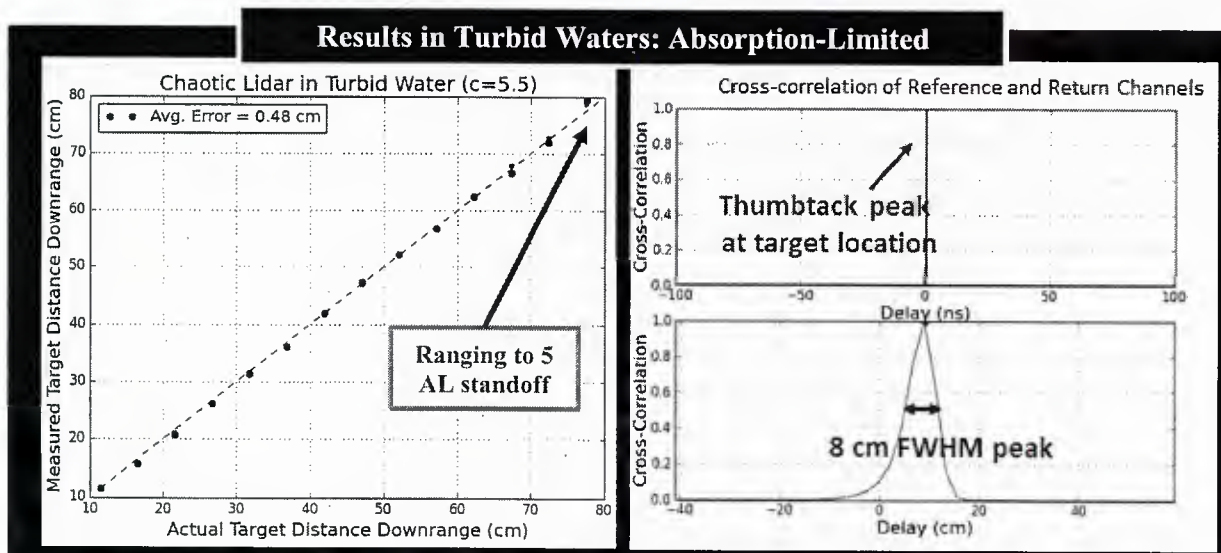

Figure 2. Ranging results in turbid water. *Left:* Ranging out to 5 attenuation lengths (AL) standoff distance (10 AL total) with 5 mm error. *Right:* Ranging is unambiguous with ±4 cm resolution.

William D. Jemison, Professor and Chair, PO Box 5720, Clarkson University, Potsdam, NY 13699-5720
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Backscattering Suppression Experiment Preparation

The narrow field of view (FOV) of the optical receiver used in the previous experiments was sufficient to demonstrate proof-of-concept ranging performance in turbid water, but is impractical for system applications. Dr. Mullen has loaned us a large aperture, photomultiplier tube (PMT) which we will use as the receiver for scattering experiments. This high speed PMT has a 2" aperture, a wide FOV, a 1 GHz bandwidth, and a 40 dB gain.

In preparation for this experiment we have implemented several improvements to the chaotic LIDAR data collection system. These improvements will to increase the speed and ease of the data collection and allow large scale experiments to be run. We are now controlling the oscilloscope directly from Labview and performing real-time digital signal processing in Labview on the fly, with an update rate of approximately 1 second. We have also designed a new high speed receiver capable of kilohertz update rates, using an FPGA with a high-speed digitizer card. A screen show of the Labview interface is shwonn in Figure 3.
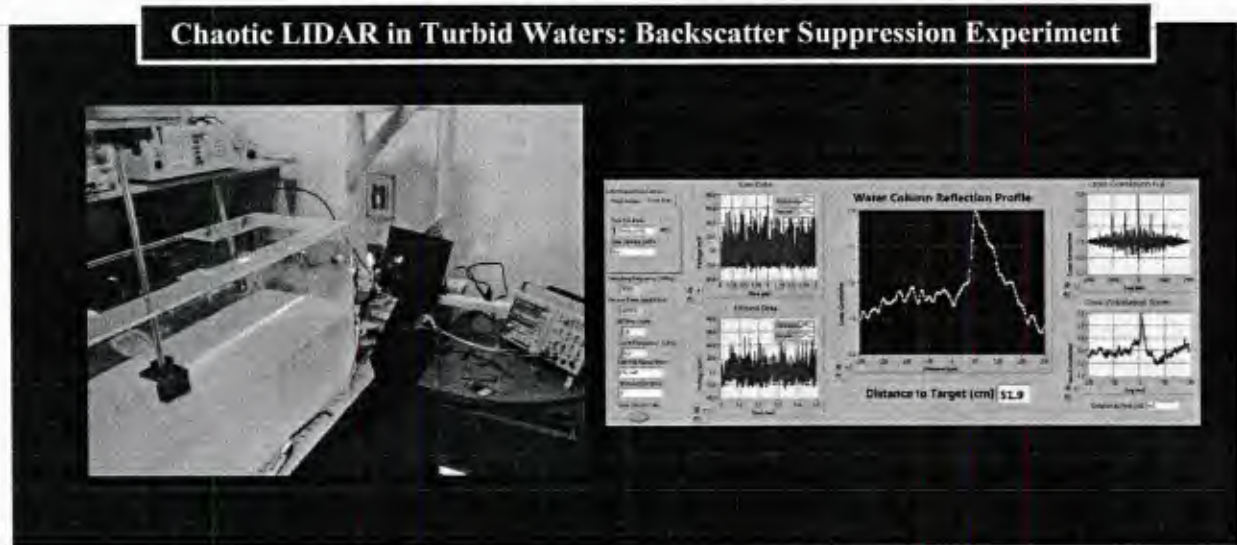

Figure 3.Backscatter suppression experiment. *Left:* Photograph of receiver using PMT. *Right:* Screenshot of real-time Labview interface.

Channel Identification using Chaotic LIDAR

We have proposed a novel experiment using the chaotic LIDAR transmitter as a probe for underwater channel identification. The basic approach is shown in Figure 4. The wideband chaotic LIDAR signal probes the underwater channel and an adaptive filter is optimized to match channel intensity modulation response. The converged adapted filter frequency response is the underwater channel response. A successful experiment would be the first experimental characterization of the optical channel over a wide bandwidth. Also, using this techniques as part of a lidar system could potentially give LIDAR transmitters on-the-fly information about the best modulation frequencies to use, and could also give insight into the content of the underwater channel.

William D. Jemison, Professor and Chair, PO Box 5720, Clarkson University, Potsdam, NY 13699-5720
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In a proof-of-concept run, a digital filter is treated as a mock "channel" and is successfully replicated using an adaptive filter optimization. Subsequent experiments have been performed, probing analog components and clean water, and the appropriate filter parameters are under investigation.

We note that in using chaotic LIDAR for channel identification, it may be possible to use advanced signal processing decomposition techniques to remove the backscatter from any target return. This is a technique used in Clarkson's frequency-domain reflectometry system, which was introduced at this year's ULI forum and the Oceans '13 conference. This approach will be investigated as an additional means of suppressing backscatter and extending the operating range of the system.
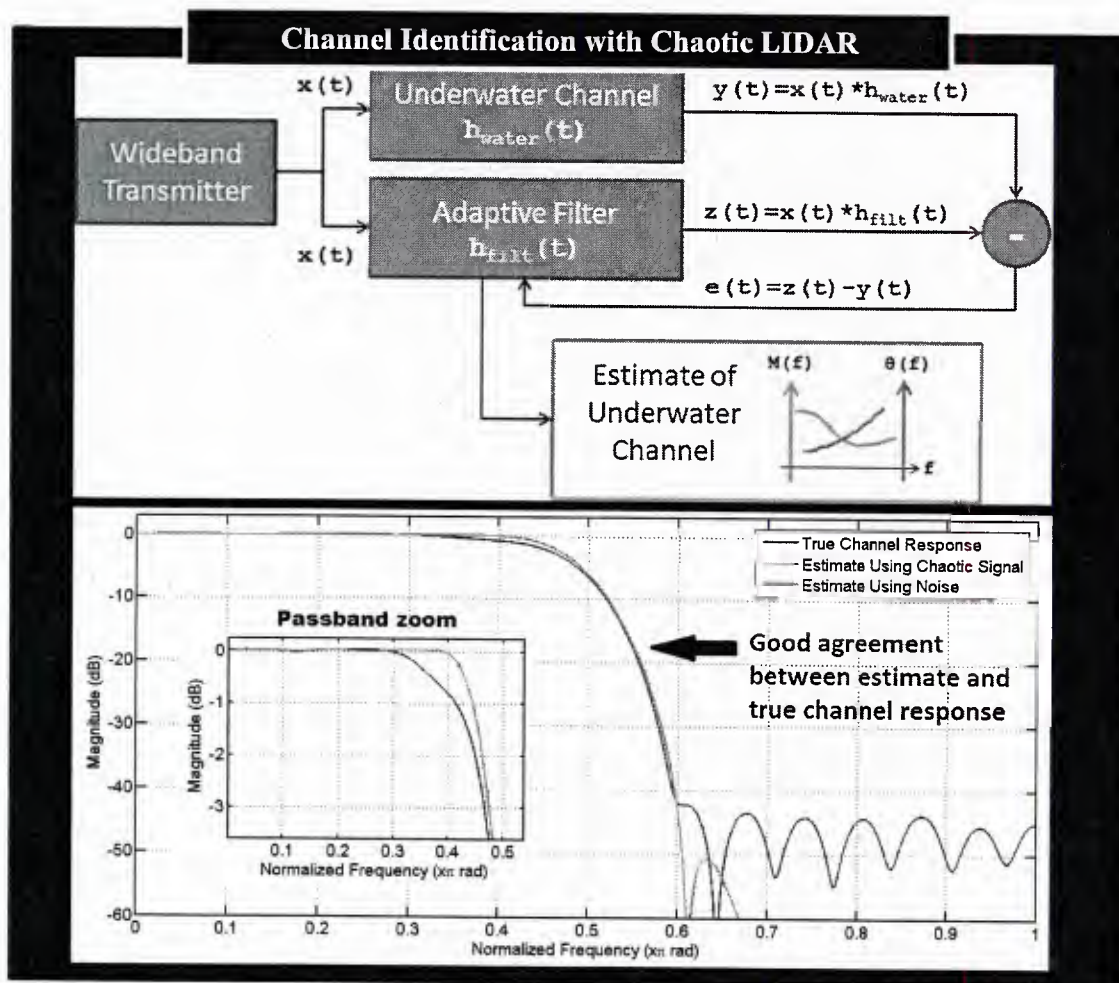

Figure 4. Channel identification. *Top:* Block diagram. The chaotic LIDAR signal is used as the wideband transmitter, and an adaptive filter estimates the underwater channel. *Bottom:* Proof of concept using chaotic signal to estimate a digital filter's response.

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Oceans 2013 Student Poster Competition

Clarkson Ph.D. candidate Luke Rumbaugh was invited to compete in the Student Poster Competition at IEEE/MTS Oceans '13, and received Second Place honors for our poster "A 532 nm Chaotic Lidar Transmitter for High Resolution Underwater Ranging and Imaging". Shown below is the award recognition ceremony with the presidents of the Oceanic Engineering Society (OES) and the Marine Technology Society (MTS).

Figure 5. Oceans '13 Student Poster Competition. *Left:* Luke Rumbaugh at award ceremony with OES president Rene Garello and MTS president Drew Michel. *Right:* The poster competition featured 20 student posters from five countries, out of 100 initial submissions.

III. Short Work Statement for FY14 Q2

In the next quarter, we will complete setup for the backscatter suppression experiment using a large-aperture receiver. We will execute this experiment to demonstrate the degree to which chaotic LIDAR allows backscatter suppression, and establish its baseline performance in turbid waters.

We also plan to integrate the high-speed embedded system receiver with the chaotic LIDAR transmitter to allow high performance ranging in real-time with a compact receiver.

We also expect our 20m test tank to be operational.

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